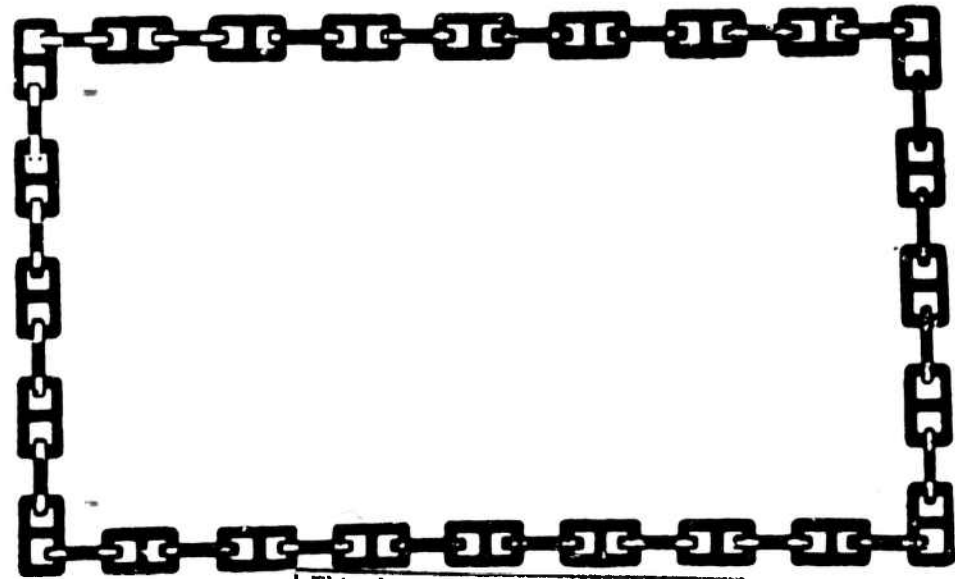


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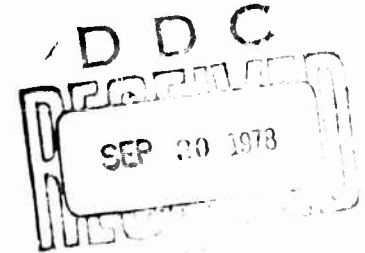
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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 14-78

EVALUATION OF THE U.S.N. LIGHTWEIGHT
DIVING MASK (JACK BROWNE)

JAMES R. MIDDLETON

JUNE 1978

Approved for public release; distribution unlimited

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Glossary

<u>Abbreviation</u>	<u>Definition</u>
ACFM	actual cubic feet per minute
BPM	breaths per minute
Cm H ₂ O	centimeters of water pressure (differential)
fsw	feet of seawater
I.D.	inside diameter
LPM	liters per minute (flow rate)
NEDU	Navy Experimental Diving Unit
O/B	over bottom pressure
ΔP	pressure differential
psid	pounds per square inch differential
psig	pounds per square inch gauge
RHCU	Reserve Harbor Clearance Unit
RMV	respiratory minute volume in LPM
USN	United States Navy

Abstract

The U.S.N. Lightweight Diving Mask (Jack Browne) was tested unmanned by NEDU in May 1978 in accordance with reference 1. The tests evaluated mask flow rates and breathing resistance at varying O/B pressures. Results predict the mask would support light and moderate diver work rates but is incapable of supporting a hard working diver even at shallow depths. The Jack Browne therefore does not meet the basic requirement of supporting a diver in an emergency situation or safely performing heavy work at any depth.

I. INTRODUCTION

In May 1978 NEDU performed unmanned testing on the Jack Browne lightweight diving mask in accordance with reference 1. The mask is of the full face/free flow type with umbilical air supply. It has been used successfully for decades as the mainstay of shallow surface supported diving. However, the antiquated design of both the air supply and exhaust valves has caused concern regarding its ability to support a hard working diver safely at the low O/B supply pressures available from some compressors. This test series was therefore initiated in order to objectively determine the operational characteristics of the Jack Browne mask. It is currently manufactured by Desco Corporation, 242 N. Milwaukee Street, Milwaukee, Wisconsin 53202.

Two separate tests were conducted: Test No. 1 was to establish mask flow rates at various console O/B supply pressures and depths. Test No. 2 measured breathing resistance at various work rates and console O/B supply pressures. Umbilical pressure drop was also monitored as a supplementary guide to evaluation during the first test series.

II. TEST PROCEDURE

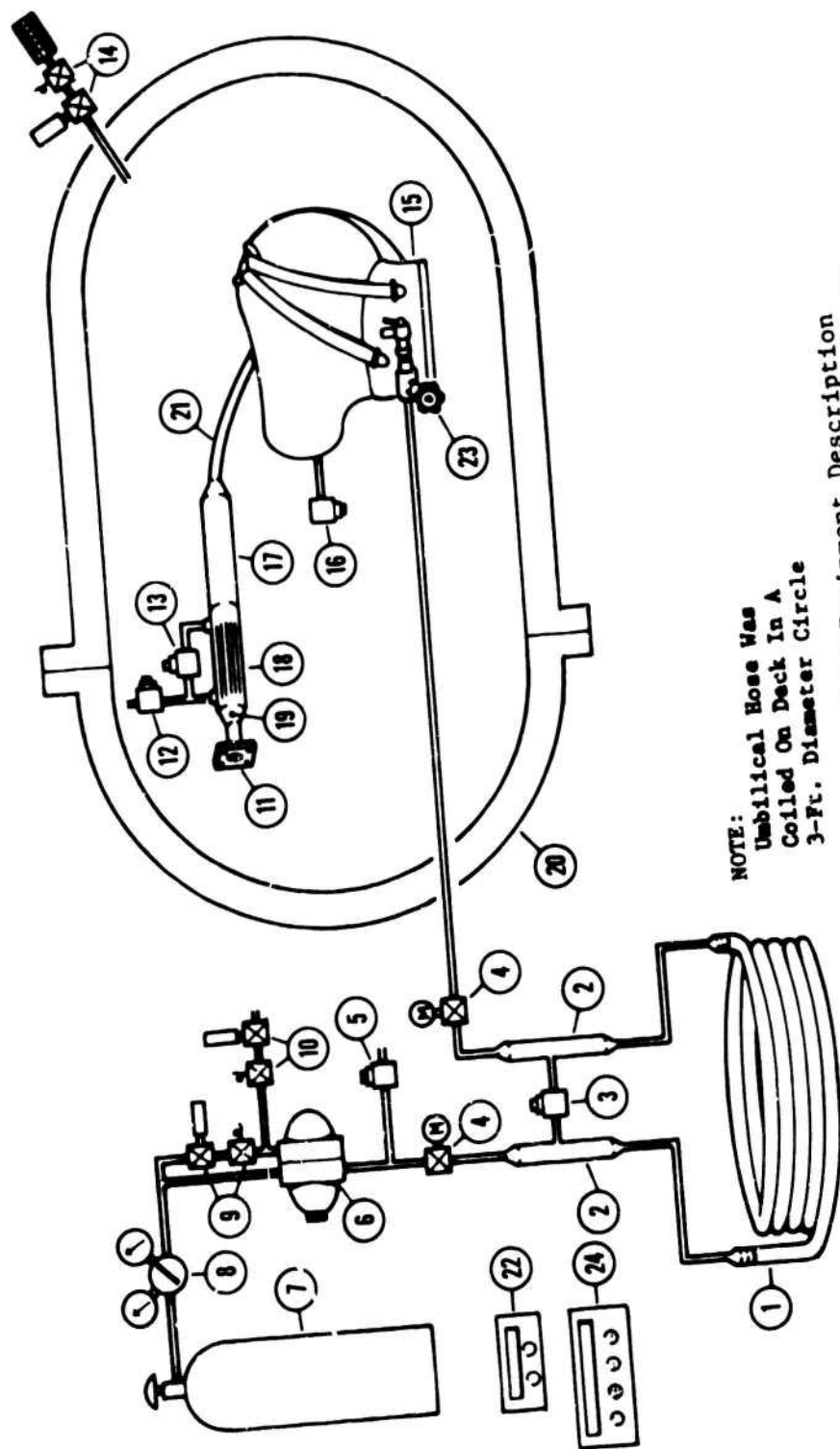
A. Test Plan

NEDU test equipment was set up as shown in Figures 1 and 2. The actual test plans are given in Appendix A and B. A breathing machine simulated diver inhalation and exhalation at various depths and a laminar flow element measured the air flow rate to the mask at various O/B supply pressures. The instrumentation and test equipment shown in Figures 1 and 2 is listed in Appendix C and D respectively. Parameters which were controlled, measured and plotted are listed below.

B. Controlled Parameters

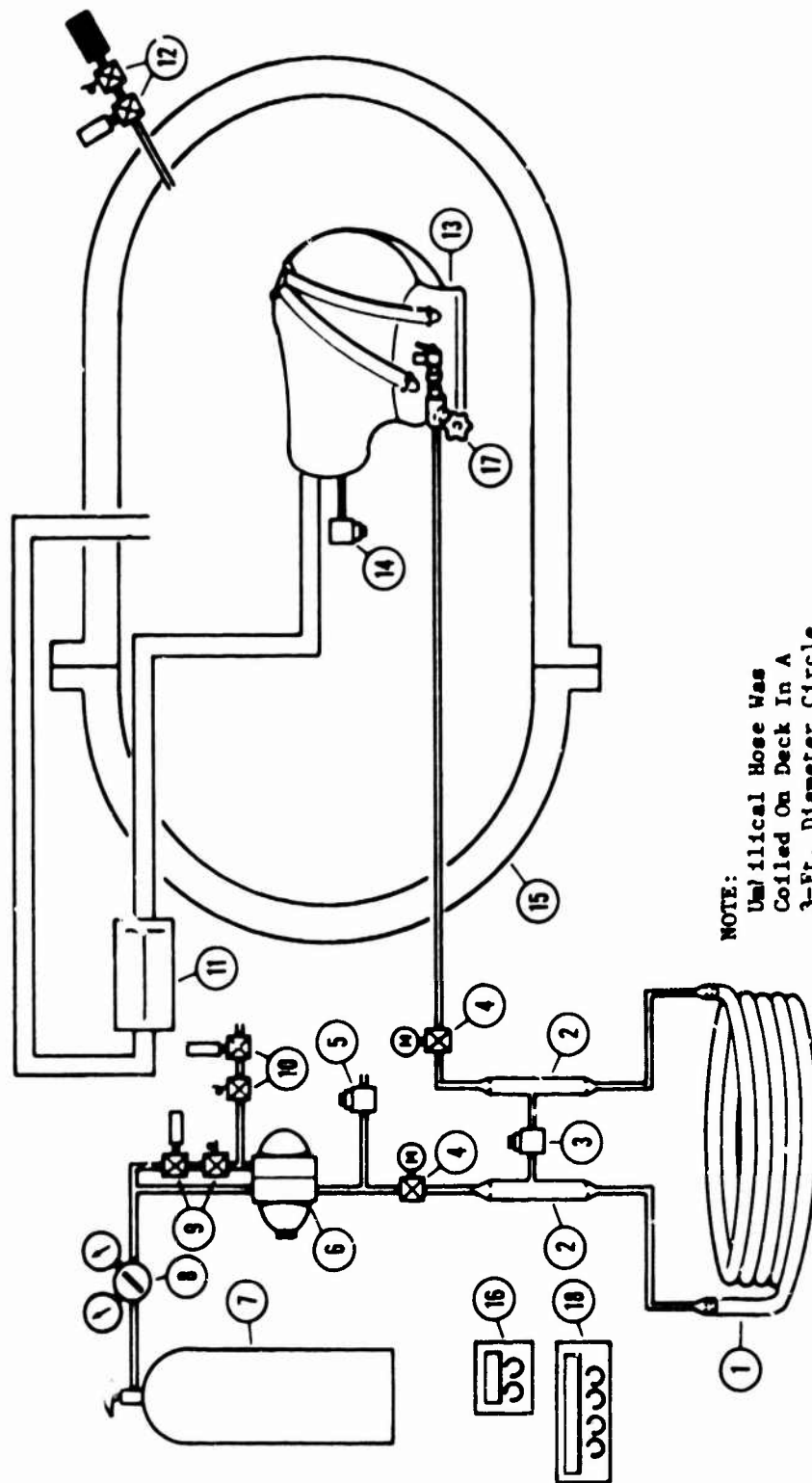
The following parameters were controlled during the Jack Browne tests.

1.	Breathing Rate	/ Tidal Volume	/ RMV	/ Diver Work Rate
(a)	15 BPM	1.5 liters	22.5 LPM	Light
(b)	20 BPM	2.0 liters	40.0 LPM	Moderate
(c)	25 BPM	2.5 liters	62.5 LPM	Moderately Heavy



NOTE:
Umbilical Hose Was
Coiled On Deck In A
3-Ft. Diameter Circle
(See Appendix C For Complete Equipment Description
Equipment Numbers Correspond To Those In Appendix C)

FIGURE 1. TEST 1. JACK BROWNE FLOW AND UMBILICAL PRESSURE DROP



(See Appendix D For Complete Equipment Description
Equipment Numbers Correspond To Those In Appendix D)

FIGURE 2. TEST 2. JACK BROWNE BREATHING RESISTANCE

- | | | | | |
|-----|--------|------------|----------|---------|
| (d) | 30 BPM | 2.5 liters | 75.0 LPM | Heavy |
| (e) | 30 BPM | 3.0 liters | 90.0 LPM | Extreme |

2. Exhalation/Inhalation time ratio: 1.0/1.0
3. Breathing waveform: sinusoid
4. Umbilical gas supply pressure: 25 to 125 psig O/B in 25 psig increments
5. Supply gas: air
6. Incremental depth stops: 0, 15, 30, 60 and 90 FSW
7. Mask supply valve position: wide open
8. Chamber temperature: ambient

C. Measured Parameters

The following parameters were measured on the Jack Browne tests

1. Inhalation maximum ΔP (cmH₂O)
2. Exhalation maximum ΔP (cmH₂O)
3. ΔP vs. tidal volume plots
4. Dynamic pressure drop across 100 foot umbilical (psig)
5. Mask air flow rate (ACFM)
6. Air temperature out of laminar flow element for temperature calibration of flow meter

D. Data Plotted

The following data are plotted in this report.

1. Inhalation maximum ΔP vs. depth at each RMV tested
2. Exhalation maximum ΔP vs. depth at each RMV tested

3. Umbilical pressure drop vs. console O/B supply pressure at each depth tested

4. Mask flow vs. depth at each O/B supply pressure tested

III. RESULTS AND DISCUSSION

A. Description

The USN Lightweight Diving Mask (Jack Browne) is an open circuit, free flowing full face mask. It is designed solely for surface supplied umbilical diving at shallow depths. The mask incorporates a gas supply valve, located on the right side of the mask, with which the diver can control gas flow rate. A small deflector directs air flow across the face plate to prevent fogging. Air is exhausted through a simple mushroom type flapper valve on the left side of the mask.

The air supply umbilical attaches to the mask at the air control valve assembly. The control valve also houses a non-return valve in the umbilical port. Normally a 5/16 inch I.D. umbilical with a working pressure of 150 psig is used to supply air to the diver.

The mask is constructed of molded rubber with a double-edged face seal. It is held in place with an adjustable five point head harness.

B. TEST NO. 1: Mask Flow Rate and Umbilical Pressure Drop Tests

1. Mask Flow Rate Test: Flow rates on the Jack Browne mask were measured at overbottom pressures varying from 25 to 125 psig. Depths ranged from 0 to 90 FSW. The mask supply valve was left in the wide open position for all tests.

In order to support a diver's respiratory needs at heavy work rates (75 RMV), a mask flow of 10 ACFM should be available since the Jack Browne has no compliant volume such as that found in full helmets with neck dams or dry suits. Consequently, no higher O/B supply pressure was tested at a given depth when 10 ACFM or greater was achieved.

Figure 3 shows change of flow with depth at the various overbottom pressures tested. Twenty-five psig O/B produced 6 ACFM on the surface but only 2.4 ACFM at 90 FSW. At 50 psig O/B 11.8 ACFM was achieved on the surface but it was reduced to 4.7 ACFM at 90 FSW.

An overbottom pressure of 75 psig produced flows in excess of 12 ACFM at 15 FSW and 6.7 ACFM at 90 FSW. 100 and 125 psig O/B pressures were tested only at 60 and 90 FSW because of the extremely

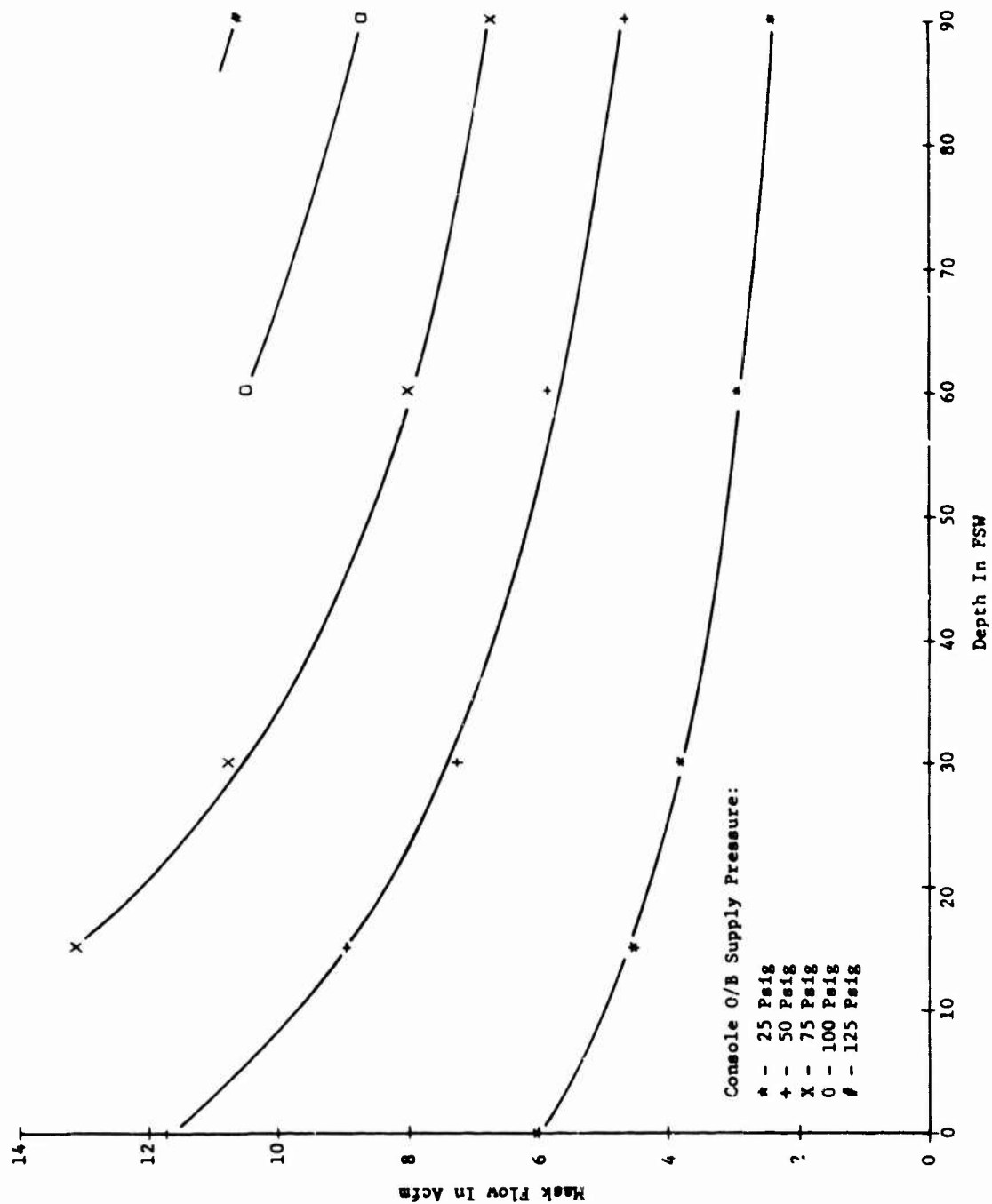


FIGURE 3. JACK BROWNE MASK FLOW TEST

high flow rates they would produce at shallower depths. A pressure transducer mounted in the mask during these tests indicated that mask pressures became excessive (in excess of 25 cmH₂O) at flow rates over 10 ACFM. This is the result of the exhaust valve's inability to handle large volumes of gas.

In general, the mask supply valve was found to supply large volumes of air regardless of depth at supply pressures between 50 and 100 psig O/B. However, the exhaust valve is inadequate and generates high mask positive pressures when enough gas is supplied to support a hard working diver's respiratory needs. Moreover mask positive pressure will tend to "blow" the mask off of the divers face.

2. Umbilical Pressure Drop Test: The Jack Browne mask is used in conjunction with a special 5/16 inch I.D. oxygen hose. A pressure transducer mounted across the inlet and outlet of two 50 foot sections of hose was used to monitor umbilical pressure loss at each overbottom pressure tested. Figure 4 gives a synopsis of the results of these tests. Data applies only to a 100 foot length of umbilical. Longer lengths will have greater losses. However, these can be determined from Figure 4 since umbilical pressure drop is directly proportional to umbilical length.

The pressure drop at a given console O/B supply pressure was independent of depth. Pressure losses were extremely high in relation to console O/B pressures due to the small I.D. of the umbilical. However, the porting in the mask supply valve is adequate to produce satisfactory flows at low driving pressures. For example, with a console O/B supply pressure of 50 psig, the actual diving pressure at the mask supply valve was reduced to approximately 20 psig O/B due to almost 30 psig hose loss.

C. TEST NO. 2: Breathing Resistance Tests

Based upon the results of the mask flow tests, it was decided to use a console supply pressure of 50 psig O/B as a starting point for measuring mask breathing resistance at depth. The mask was tested at breathing rates simulating light to extreme work conditions. Test procedures dictated that when inhalation resistance became excessive at a given depth, console O/B supply would be increased over 50 psig O/B in 25 psig increments until a reasonable value was obtained. This procedure was followed except in cases where the higher flow rates caused exhalation resistance to increase rapidly. At this point the test was terminated.

Table 1 gives a summary of the results of the breathing resistance tests. Figures 5 and 6 show in detail how O/B pressure affected breathing resistance at 40 and 75 RMV respectively. At 22.5 and 40.0 RMV (Figure 5)

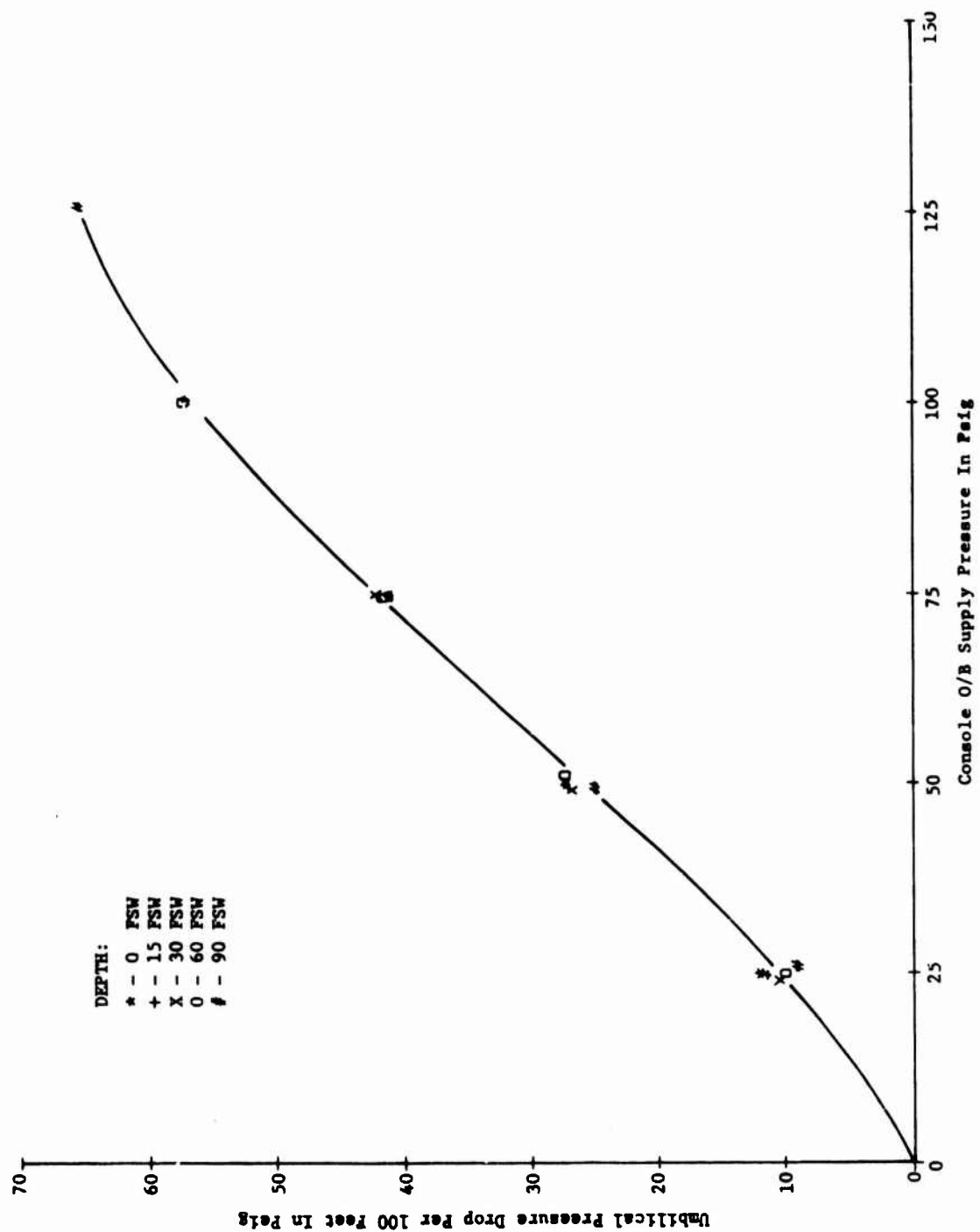


FIGURE 4. JACK BROWNE UMBILICAL PRESSURE DROP TEST

TABLE 1

DEPTH (FSW)	RMV (LPM)	22.5	40.0	62.5	75.0	90.0
	BREATHING RESISTANCE	EXHALATION	EXHALATION	EXHALATION	EXHALATION	EXHALATION
		INHALATION	INHALATION	INHALATION	INHALATION	INHALATION
0		<u>19.6</u> 11.6	<u>22.9</u> 9.1	<u>28.2</u> 6.3	<u>31.8</u> 4.7	<u>36.4</u> 2.6
15		<u>19.0</u> 9.8	<u>22.4</u> 6.4	<u>30.0</u> 3.4	<u>40.3</u> -13.9	<u>39.7</u> -23.7
30		<u>19.1</u> 8.1	<u>23.3</u> 4.6	<u>31.5</u> 0.0	<u>45.3</u> -48.3	NA
60		<u>18.4</u> 6.0	<u>24.6</u> 2.2	<u>35.3</u> -91.3	NA	↓
90		<u>15.4</u> 4.7	<u>25.9</u> 0.4	NA	↓	↓

Breathing Resistance In Cm H₂O @50 PSIG Console O/B Supply Pressure

DEPTH (FSW)	RMV (LPM)	22.5	40.0	62.5	75.0	90.0
	BREATHING RESISTANCE	EXHALATION	EXHALATION	EXHALATION	EXHALATION	EXHALATION
		INHALATION	INHALATION	INHALATION	INHALATION	INHALATION
0		NA	NA	NA	NA	NA
15		↓	↓	↓	↓	<u>54.3</u> 4.8
30		↓	↓	↓	<u>49.1</u> 3.1	<u>57.9</u> 0.2
60		↓	↓	<u>45.1</u> 0.4	<u>53.9</u> -6.0	NA
90		↓	↓	<u>47.7</u> -33.9	<u>>60.0</u> ->-100.0	↓

Breathing Resistance In Cm H₂O @75 PSIG Console O/B Supply Pressure

DEPTH (FSW)	RMV (LPM)	22.5	40.0	62.5	75.0	90.0
	BREATHING RESISTANCE	EXHALATION	EXHALATION	EXHALATION	EXHALATION	EXHALATION
		INHALATION	INHALATION	INHALATION	INHALATION	INHALATION
0		NA	NA	NA	NA	NA
15		↓	↓	↓	↓	↓
30		↓	↓	↓	↓	↓
60		↓	↓	↓	↓	<u>77.6</u> -0.6
90		↓	↓	<u>60.4</u> 1.8	↓	NA

Breathing Resistance In Cm H₂O @100 PSIG Console O/B Supply Pressure

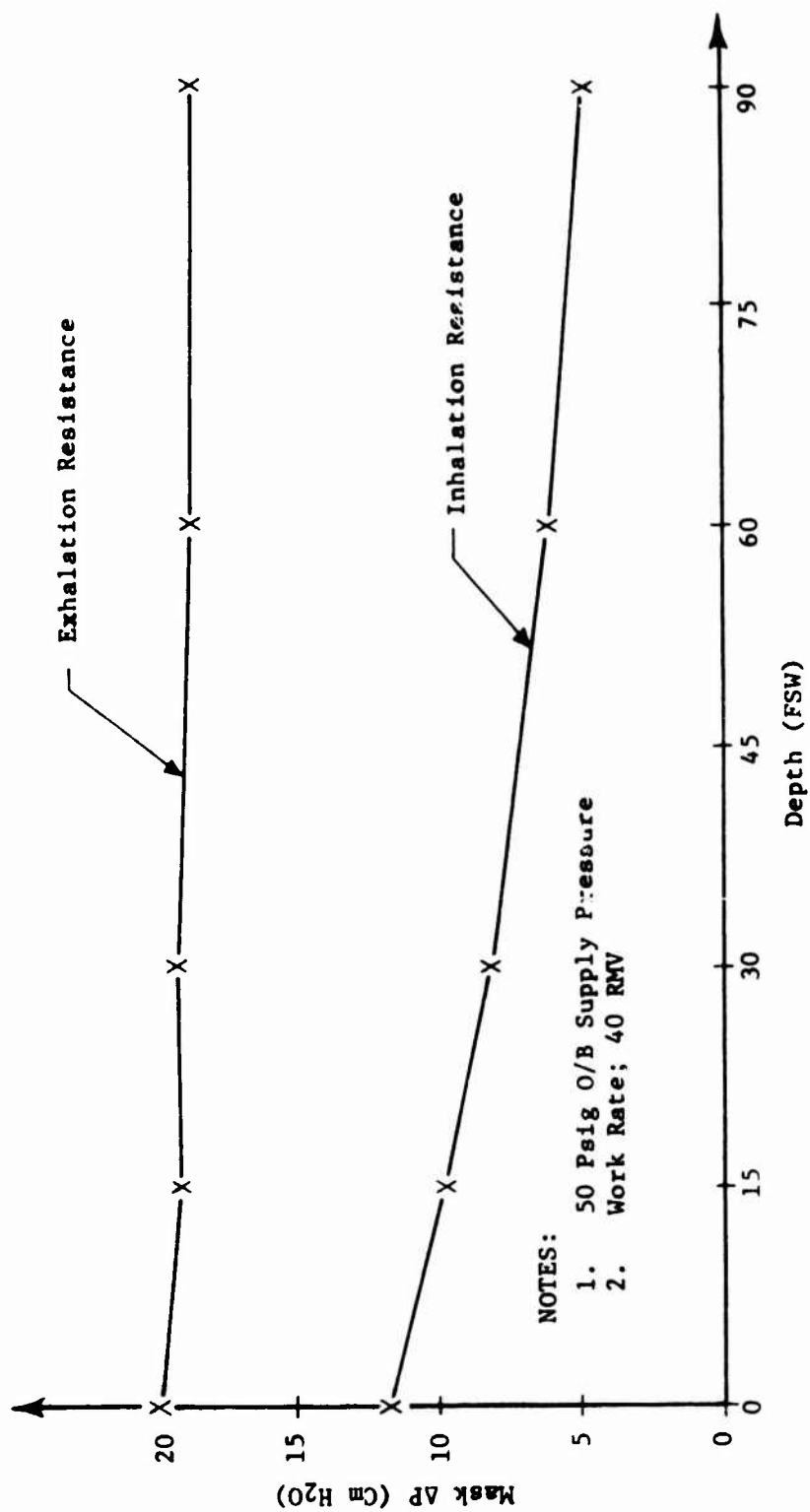


FIGURE 5. JACK BROWNE BREATHING RESISTANCE AT 40 RMV

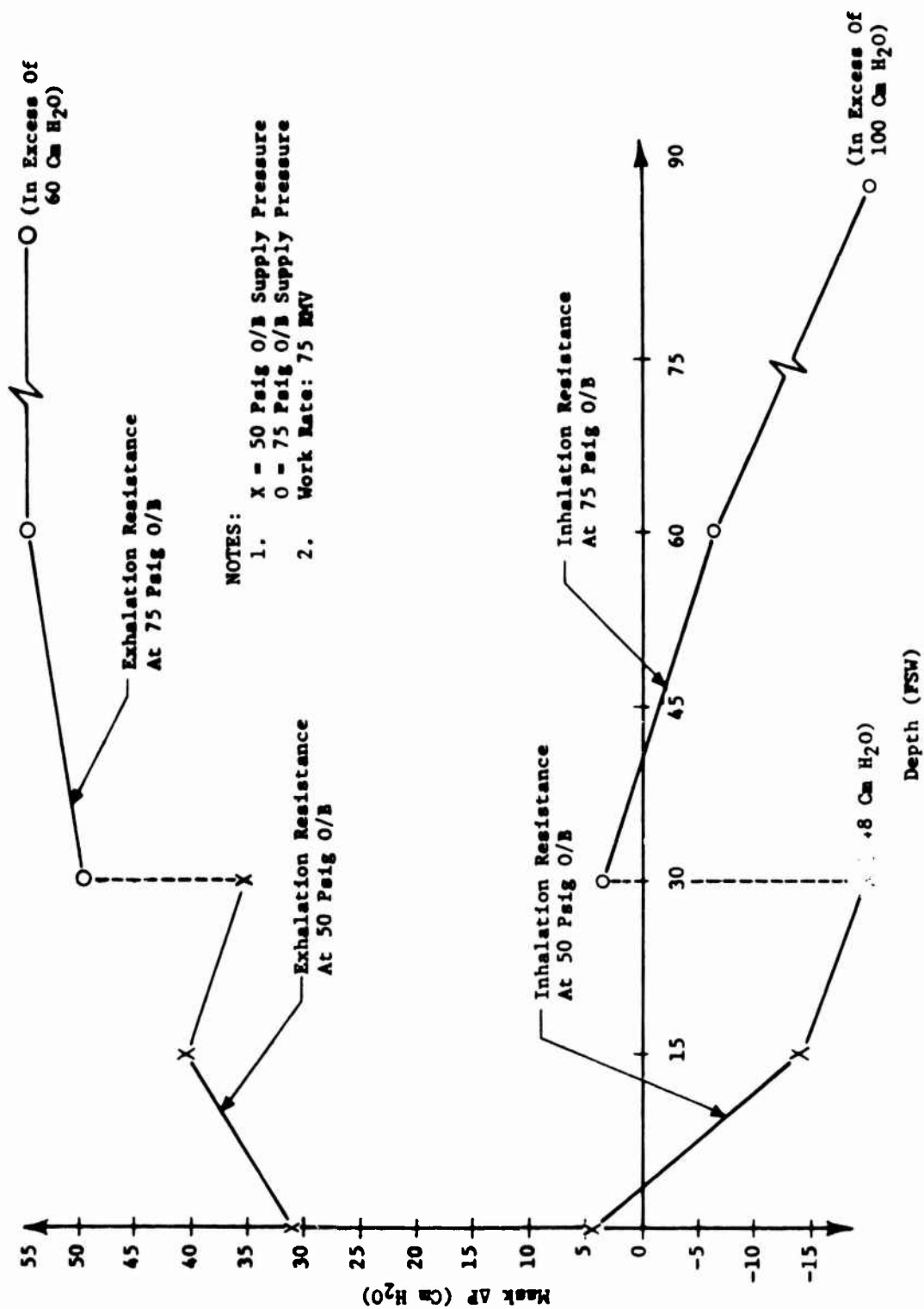


FIGURE 6. JACK BROWNE BREATHING RESISTANCE AT 75 RMV

inhalation and exhalation resistance was acceptable from the surface all the way to 90 FSW with 50 psig O/B supply pressure.

With an RMV of 62.5 exhalation pressures were excessive on the surface at 62.5 RMV and increases in depth and supply pressure simply aggravated this condition. However, inhalation resistance was satisfactory at depths down to 30 FSW. At 60 FSW a supply pressure of 75 psig O/B was necessary to keep inhalation resistance low and at 90 FSW 100 psig O/B was required.

At 75 RMV (Figure 6) inhalation resistance could be kept low by increasing supply pressure as required to a depth of 60 FSW. However, exhalation pressures were again excessive even on the surface and the supply pressures required to give adequate flow for inhalation at 90 FSW produced exhalation pressures in excess of 100 cmH₂O.

Ninety RMV could not be considered safe at any depth due to the high exhalation pressures produced when mask flow rates were high enough to maintain reasonable inhalation resistance.

IV. CONCLUSIONS

A. Mask Flow Tests

The Jack Browne mask was found to have an adequately ported supply valve for operating in the pressure range of 50 to 125 psig O/B at the console. However, the mask exhaust valve is restrictive due to the small port size and the inflexible nature of the neoprene rubber mushroom valve. It is the exhaust valve which is the performance-limiting component of the mask.

B. Breathing Resistance Tests

The Jack Browne mask will probably support a diver at light to moderate work rates from the surface to 90 FSW. However, as evidenced by the breathing resistance tests at RMV's of 62.5 and above (moderately heavy to extreme diver work rates) mask performance is restrictive regardless of depth. Consequently, it cannot meet the basic requirement of being able to support a diver work level of 3.0 LPM oxygen consumption (75 RMV). This requirement applies to all diving life support equipment currently used by the USN and is considered the minimum to support a diver in an emergency situation.

C. Jack Browne/RHCU Compressor Compatibility

As evidenced from Figure 5, a console supply pressure of 50 psig O/B is adequate to support the Jack Browne mask to 90 FSW at moderate work rates. This translates to an actual required minimum mask flow of

5 ACFM (Figure 3) or 18.64 SCFM at 90 FSW to meet respiratory needs at 40 RMV and 90 FSW. Since the output of the AAI-325 compressor is only 16.0 SCFM (reference b), the maximum operating depth would be 60 FSW (one diver) and 20 FSW (two divers). It is important to understand that these are the maximum possible operating limits for moderate work only and do not meet basic requirements for safe diving.

The RHCUC compressor's ability to support divers in the Jack Browne mask at heavy work (75 RMV) is extremely limited. Since a mask flow of 10 ACFM is required to support an RMV of 75 LPM, the maximum operating depth for one diver at heavy work would be 20 FSW. However, at RMV's over 40 the mask exhalation resistance is prohibitive when flow rates are sufficient to meet respiratory demands. Consequently, the compressors ability to support heavy work with adequate flows is not the limiting factor with respect to the Jack Browne mask. The complete operating characteristics of the RHCUC compressor are given in Appendix F.

V. REFERENCES

Reference

Credit

1

Task No. 78-3 from NAVSEA OOC-3 to CO, NEDU,
Subject: Conduct flow measurements at various
depths and work rates to determine Jack
Browne diving limits for RHCUC units receiving
RHCUC compressors.

2

SUPDIVE Report No. 2-77, "Preliminary Evaluation
of a Compressed Air Breathing Supply System for
Reserve Harbor Clearance Unit Use," Battelle
Memorial Institute, J.G. Yates, J.E. Hill,
J.A. Henkener, 9 September 1977.

APPENDIX A

TEST PLAN FOR JACK BROWNE MASK FLOW AND UMBILICAL PRESSURE DROP TESTS (SEE FIGURE 1)

1. Install Jack Brown mask in chamber 1 and instrument as shown in Figure 3.
2. Calibrate all sensors.
3. Record all transducer zero shifts.
4. Adjust console pressure in increments of 25 psig O/B from 25 to 125 psig.

NOTE

Terminate incremental steps
if mask pressure becomes
excessive or if mask flow
exceeds 10 ACFM.

5. Read, record, and store data at each console pressure.
6. Close chamber and compress to 15 FSW.
7. Repeat steps 3 through 5.
8. Compress chamber to 30 FSW.
9. Repeat steps 3 through 5.
10. Compress chamber to 60 FSW.
11. Repeat steps 3 through 5.
12. Compress chamber to 90 FSW.
13. Repeat steps 3 through 5.
14. Decompress chamber.
15. Open chamber.

APPENDIX B

TEST PLAN FOR JACK BROWNE BREATHING RESISTANCE TESTS (SEE FIGURE 2)

1. Remove LFE and reinstall exhaust valve on mask with 1 inch tygon transition piece.
2. Record all transducer zero shifts.
3. Adjust console pressure to 50 psig O/B pressure (if inhalation resistance is excessive, increase console pressure in 25 psig increments)
*See Note.
4. Adjust Breathing Machine (B/M) to 15 BPM, and 1.5 liters tidal volume.
5. Read, record and store data.
6. Repeat step 18.
7. Adjust B/M to 20 BPM, and 2.0 liters tidal volume.
8. Repeat step 20.
9. Repeat step 18.
10. Adjust B/M to 25 BPM and 2.5 liters tidal volume.
11. Repeat step 20.
12. Repeat step 18.
13. Adjust B/M to 30 BPM and 2.5 liters tidal volume.
14. Repeat step 20.
15. Repeat step 18.
16. Adjust B/M to 30 BPM and 3.0 liters tidal volume.
17. Repeat step 20.
18. Close chamber and compress to 15 FSW.
19. Repeat steps 17 through 30.
20. Compress chamber to 30 FSW.

21. Repeat steps 17 to 30.
22. Compress chamber to 60 FSW.
23. Repeat steps 17 through 30.
24. Compress chamber to 90 FSW.
25. Repeat steps 17 through 30.
26. Decompress chamber.
27. Disassemble test setup.

*NOTE: If inhalation or exhalation resistance remains excessive at elevated console pressure, delete the higher RMV runs.

APPENDIX C

TEST EQUIPMENT FOR MASK FLOW TESTS (TEST NO. 1)

(Note: Equipment numbers correspond to that in Figure 1.)

1. 2-50 foot lengths of 5/16" I.D. air supply umbilical
2. Gas flow straightener
3. Validyne pressure transducer with 50 psid diaphragm (1 ea) to measure umbilical pressure drop
4. Motorized valve
5. Validyne pressure transducer with 250 psid diaphragm (1 ea) to measure O/B supply pressure
6. Dome loaded pressure regulator
7. Gas supply
8. High pressure regulator
9. Micrometer valve and solenoid for loading dome regulator
10. Micrometer valve and solenoid for unloading dome regulator
11. Jack Browne mask exhaust valve
12. Validyne pressure transducer with 0.5 psid diaphragm (1 ea) to measure pressure across mask exhaust valve
13. Validyne pressure transducer with 0.1 psid diaphragm (1 ea) to measure pressure drop across laminar flow element
14. Depth keeping solenoid valve
15. Jack Browne lightweight diving mask
16. Validyne pressure transducer with 1.0 psid diaphragm (1 ea) to measure pressure in Jack Browne mask
17. Gas flow straightener
18. Merriam 40 SCFM laminar flow element

19. Yellow springs instruments thermistor model 731 and readout (1 ea) for temperature calibration of laminar flow element
20. Hyperbaric chamber complex
21. 1 inch I.D. tygon tubing
22. Validyne transducer readout (5 ea)
23. Mask supply valve
24. Hewlette Packard HP 9825A Data acquisition system

APPENDIX D

TEST EQUIPMENT FOR BREATHING RESISTANCE TESTS (TEST NO. 2)

(Note: Equipment numbers correspond to those in Figure 2.)

1. 2-50 foot lengths of 5/16" I.D. air supply umbilical
2. Gas flow straightener
3. Validyne pressure transducer with 50 psid diaphragm (1 ea) to measure umbilical pressure drop
4. Motorized valve
5. Validyne pressure transducer with 250 psid diaphragm (1 ea) to measure O/B supply pressure
6. Dome loaded pressure regulator
7. Gas supply
8. High pressure regulator
9. Micrometer valve and solenoid for loading dome regulator
10. Micrometer valve and solenoid for unloading dome regulator
11. Breathing machine
12. Depth keeping solenoid
13. Jack Browne lightweight diving mask
14. Validyne pressure transducer with 1.0 psid diaphragm (1 ea) to measure mask breathing resistance
15. Chamber complex
16. Validyne transducer readout (3 ea)
17. Mask supply valve
18. Hewlette Packard HP 9825A Data Acquisition System

APPENDIX E

MAN-HOURS REQUIRED

The man-hours required for the evaluation of the USN Lightweight Diving Mask (Jack Browne) are computed below.

	<u>Men</u>	<u>Hours</u>	<u>Man-Hours</u>
Test Set-up	2	3	6
Test Operation	2	4	8
Chamber Operation	1	4	4
Post Test Clean-up	1	2	2
Data Reduction/Report Production	1	40	40
Duplicating	4	30	<u>120</u>
TOTAL			180

APPENDIX F

RHCU COMPRESSOR CHARACTERISTICS

1. Manufactured by Aqua-Air Industries
2. Model Number AAI-325 (compressor/engine combination)
3. Compressor specifications:
 - a. Manufactured by Quincy Compressor Division of Colt Industries
 - b. Model Number 325
 - c. Two stage
 - d. Air-cooled
 - e. Oil lubricated (pressure supply)
 - f. 900-300 RPM operating range
 - g. 500 psig maximum operating pressure (intermittant)
 - h. 200 psig maximum operating pressure (continuous)
 - i. Rated output flow: 16 SCFM at 200 psig
4. Diesel engine specifications:
 - a. Petter type BA heavy d v
 - b. Oil cooled
 - c. Single cylinder
 - d. Compression ignition
 - e. 4-cycle
 - f. 3.5 inch base x 3.625 inch stroke
 - g. 10 brake horsepower at 3000 RPM
 - h. Compression ratio 18.5:1
 - i. Manual start

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The author would like to express his sincere appreciation to Mr. G.W. Noble and the personnel of the Naval Coastal Systems Center Hydrospace Laboratory.

In addition to the generous use of their sophisticated test facility, the high level of technical expertise, and tireless effort were instrumental to the successful and timely completion of these tests.